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# Request for grant of a patent

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| 2. | Patent application number *(The Patent Office will fill in this part)* | 0227635.0 |
| 3. | Full name, address and postcode of the or of each applicant *(underline all surnames)* | Dr. Christopher Paul HANCOCK<br>61 Bryants Hill<br>St. George<br>Bristol<br>BS5 8QZ<br>United Kingdom |
| | Patents ADP number *(if you know it)* | 8514598001 |
| | If the applicant is a corporate body, give the country/state of its incorporation | |
| 4. | Title of the invention | An Advanced Technology Electrosurgical System To Enable Effective Treatment of Cancerous Growths Manifested In Vital Organs of the Human Body |
| 5. | Name of your agent *(if you have one)* | |
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# An Advanced Technology Electrosurgical System

# To Enable Effective Treatment of Cancerous Growths

# Manifested In Vital Organs of the Human Body

## 1. Introduction:

This document describes the possible development and implementation of a complete advanced technology microwave system that could be used for treating various types of cancerous growths manifested in vital organs contained in the human body.

Recent research has demonstrated that the application of heat energy to tissue is an effective method of killing cells [pa1] – [pa10]. As tissue temperatures rise above 113F (60°C to 65°C) protein is permanently damaged and cell membranes fuse, causing cell death.

The proposed system will provide a localized source of energy to instantly ablate (destroy) the cancerous tissue. Microwaves are delivered through the electrode (instrument, probe, antenna), which can be placed in tissue around the tumor. The instant heat generated by the microwave energy should also dehydrates the cells that surround the tumor, thus preventing excessive blood loss. Cancerous tumors killed in this manner should lead to minimal side effects and cause less general patient discomfort than that caused by traditional chemotherapy.

In basic form, the system consist will consist of a fully controllable power amplifier operating over the frequency range of between: 14GHz and 14.5GHz, which uses state of the art Gallium Aluminium Arsenide Field Effect Transistor (*GaAs* FET) devices in the output power stage, and a range of treatment instruments.

Coupled with the advantage of producing a system that can be precision controlled in terms of power and operating frequency, the GaAs FET power stage solid state

# Patent Application

## An Advanced Technology Electrosurgical System To Enable Effective Treatment of Cancerous Growths Manifested In Vital Organs of the Human Body

**Inventor: Dr C.P. Hancock**

**Co-Inventor: Dr A.M. Goodman**

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solution provides a platform for the development of a portable, low cost system that can be powered from a low voltage switch mode DC power supply or a battery pack.

The specific design of the instruments is dependent upon both the particular characteristics of the cancerous growth being considered and the surrounding tissue. These characteristics include: size or volume (area and depth), texture, location, and the electrical characteristics and power absorption peaks over the frequency band of operation.

The initial target areas considered for treatment are envisaged to be small, hence the requirement for fine precision instruments, such as those that use miniature semi-rigid co-axial structures, whose diameters are small enough such that they support only a pure transverse electromagnetic (TEM) mode for energy propagation at the frequencies of interest. These instruments will be electrically impedance matched into the tissue being treated to enable efficient energy transfer. They may be used in open-surgery procedures where fine, delicate tissue structures are being treated, i.e. those in the brain, nose and throat. It may be noted here that such instruments could also be used in general heart surgery, where ultra fine structures have to be considered. In this application, the ability of the high frequency to enable fast coagulation, in order to stop bleeding when small blood vessels are damaged, could be most beneficial to the surgeon.

Micro-miniature co-axial instruments will also be developed that enable treatment via keyhole surgery; in this case the outer diameter of the instrument will be less than 1mm. It is envisaged that the distal end will be terminated with a pointed cone of high permittivity, low loss microwave ceramic material in order to concentrate the electric field distribution at the tip. This construction would provide a very high density energy source that could be used to channel through an organ, i.e. the lung or breast, cau[illegible] minimal damage en route. When the target area is reached the power level could be increased to enable the cancerous tissue to be eradicated via a short burst of very high-energy radiation. The dominant energy transport mechanism used to get the probe to the cancerous site and that used to destroy the cancerous cells would be radiation. The channel used to reach the cancerous site will be small enough to enable the damaged tissue to heal quickly, causing the patient minimal stress.

The miniature co-axial structures considered here should be constructed using materials that have low loss characteristics at frequencies of between: 14GHz and 14.5 GHz. This is most important for the longer instruments used in keyhole surgery, since conductor and dielectric losses lead to instrument heating, thus to possible energy transportation via conduction and associated increased thermal margins and collateral damage. Therefore, customized low loss (high Q) microwave dielectric material, such as microwave ceramic, will be needed to fill the cavity between the center conductor and the outer conductor, and high conductivity pure silver wire will most likely be required for the center conductor and, possibly, the outer conductor also. Balanced-to-unbalanced quarter wavelength transformers (BALUNS) may also be required along the length of the structure in order to prevent currents from flowing along the outer conductor, causing unwanted radiation burns to the patient or the surgeon.

The system can also be used to treat cancerous growths that have already grown to a relatively large volume before commencement of treatment. In this case, waveguide structures will be used, where there is no center conductor involved in the construction. The physical geometry of the waveguide can be adapted to suit both the

characteristics of the organ being considered and those of the surrounding organs. The usual geometries are rectangular and cylindrical, but others, such as square or elliptical, are possible. The structures can be filled with low loss dielectric material (loaded), or they can have an air filled cavity (unloaded). For smaller open surgery sites, or relatively large keyhole applications, the waveguide will be loaded with a high permittivity dielectric in order to minimise the aperture size. For the initial waveguide instruments, dominant mode operation will only be considered. The effects on tissue caused by launching more exotic modes will be addressed after an initial product has been fully developed. The EM-field will be launched into the waveguide structure via an E-field probe placed a quarter wavelength from the shorted end wall of the waveguide (see figure 10). The waveguide aperture size will be designed according to the cross sectional area of the treatment zone under consideration and the energy density requirement. Energy settings and treatment time will be determined by the severity of the cancerous growth, i.e. the volume, and also the characteristics of the surrounding organs. The energy density available is limited due to the large aperture sizes that are possible. Therefore, the time necessary for the tissue to reach the required temperature will be longer (much longer than the thermal time constant of the tissue being heated), hence the dominant energy transport mechanism is more likely to be conduction, as apposed to the high energy density in the case of the miniature co-axial instrument case, where it is considered to be solely radiation. The waveguide instruments will be able to be tuned, either statically or dynamically, for the best impedance match into the tissue load over the frequency range of between 14GHz and 14.5 GHz in order to achieve the most efficient energy transfer rate . Tuning will be carried out at low power levels, i.e. 0dBm to 10dBm (1mW to 10mW) using a triple-stub tuning network. The state of the tissue being treated will be continually monito on-line, using feedback signals that contain temperature and power (forward and reflected) information. The generator output energy and application time will be adjusted accordingly.

Power matching for both the micro-miniature co-axial and waveguide instruments will take place at the generator end, between the protection circulator and the output port of the generator (see section 2.4 and figure 1). Tuning will be achieved using three tuning screws (or rods) placed either a quarter or an eighth of a wavelength apart. Initial tuning will be carried out manually, but provision will be made for this to be automated using servo driven motors (or faster electromechanical actuators). It should be noted that active, or dynamic, power tuning will only take place whilst the cancerous tissue is still alive and has not fully dried out. It is envisaged that once temperature and reflected power level information indicates that the treatment tissue is en vitro, or has dried out, then dynamic matching will cease, and power will be backed off or shut down accordingly.

## 2. System Description:

For a fuller more detailed description, the system will be broken down into the following constituent parts: Power Amplifier (PA), Pre-amplifier Stages and Power Control, Frequency Source with provision for Fine Adjustment, Triple-Stub Static/Dynamic Tuning Network and DC Voltage Output Isolator, Microprocessor/Peripherals and User Interface, Instrument Identification Circuit, DC Power Supply, Generator-to-Instrument Cable Assembly, Micro-Miniature Co-axial

Instrument Group, Larger Waveguide Instrument Group, and Future Instrument Group. Figure 1 shows how the above components are interconnected to form the overall system, and the following sub-sections address each of the components in detail:

**2.1. Power Amplifier (PA)** – This stage consists of four power GaAs FETs, which have a 1dB compression point of 43dBm over a bandwidth of between 14GHz and 14.5GHz (*Ku* band), and a power gain of 6dB. Such devices have just recently been released by Toshiba Microwave Semiconductor Group; they have been allocated the part number: TIM1414-20[1]. The power from each device is added together to provide a maximum theoretical power level of up to 49 dBm (80W) at the output of the amplifier. This will be achieved using either a single quarter wavelength microstrip power combiner, or three 90 degree, 3dB stripline couplers with 50Ω dump loads connected to the isolated ports. The combiner, together with microstrip stub and transformer networks that are required for transistor impedance matching will be fabricated on a low loss microwave material, such as: RT Duroid 5880 from Rogers Microwave [9]. The copper cladding thickness should be 2 ounces on either side. This stage will also consist of two edge-coupled microstrip couplers (co-axial or Llange couplers may also be considered), with coupling factors of either 40dB or 50dB and directivity in excess of 10dB, and a power yittrium iron garnet (YIG) circulator [10] with a 50Ω power dump load [11] connected to the third port.

The couplers are used to monitor the forward power level produced at the output of the amplifier, Pfa, and the power level returned back to the third port of the circulator, Pra. This return power will be due to one or more of the following conditions: the energy at the distal end of the instrument is not matched into the tissue load, the instrument is operating in air, the cable assembly is not connected, the instrument is not connected, or there is a fault with either the cable or the instrument. The attenuated UHF levels from the couplers will then be transformed into low frequency signals, which have a bandwidth compliant with the fastest processing time required to achieve the desired dynamic response of the amplifier control loop. The signals will be detected using zero-bias microwave diodes, and then low pass filtered and conditioned for DC offset and gain before being fed into the microprocessor.

The circulator will be primarily used to prevent high-reflected power levels, generated from a mismatched condition, from entering the output ports of the power *GaAs* FETs, which could potentially cause irreversible damage. The circulator will also be used to provide enhanced isolation for the forward and reverse monitoring signals, hence effectively increasing the directivity of the two couplers. Figures 2 and 3 illustrate the two possible embodiments for this stage; power levels shown are for the maximum output power condition and the assumption is made that the microstrip circuit board layout is loss-less. The quarter wave microstrip transformer combiner is the simplest to implement, but if one of the four power transistors became damaged or shuts down, then this would produce a mismatched condition for the other three. This is not the case when using the 3dB, 90-degree combiners, since the mismatched energy is diverted into the local dump load, which is connected to the isolated port of the coupler to which the failed transistor is connected, thus making the failure transparent to the other three transistors. The microstrip combiner has the disadvantage that large standing wave currents are set up due to the fact that the impedance of the load end is 12.5Ω, also the characteristic impedance of the ¼ wavelength line is 25Ω which leads to a rather wide track; both of these problems are

alleviated when using the 3dB, 90 degree combiner method. Another possible solution is to use two ¼ wavelength 50Ω lines, each one connected to two amplifiers and joined ¼ wavelength away at a common point (this is shown in figure 2 for completeness). Although the lines are all 50Ω, there is still 100Ω and 25Ω at the common points.

A powerful microwave layout package, such as LIBRA [2] or ACADEMY[3], will hopefully be used to carry out the transistor matching, and integrate the power combiner and the forward and reverse power monitoring couplers. The provision for a drop-in power circulator [10] and tab mount 50Ω dump load [11] will also be made when the layout is considered.

**2.2. Pre-amplifier stages and Power Control** – A line up of up to four pre-amplifier stages using Miniature Monolithic Integrated Circuits (MMICs) and one power drive amplifier is required to provide enough power to feed the four main power transistors. The exact number of pre-amplifiers is dependent upon both the gain and maximum power available from each device in the line-up; it is envisaged that four will be used in this design. A power splitter is used at the end of the line-up in order to evenly divide the drive signal going into the four power devices, sustaining a balanced 50Ω environment. The power splitter can be considered as an inverted version of the power combiner, addressed in section 2.1. Thus, it will be realised either in the form of a single quarter wavelength microstrip power splitter transformer, or three 90 degree, 3dB stripline power couplers.

If it is assumed that the microstrip circuit layout is loss-less, and that the gain of each of the four power transistors is 6dB (see data sheet for TIM1414-20), then the power required at the input of the splitter to produce maximum power (49 dBm) at output of the power amplifier would be 43dBm (20W). In order to realise this power level, a further TIM1414-20 is required for the fifth pre-amplifier (driver) stage. This implies that the first four pre-amplifier MMICs need to provide a combined maximum power level of 37dBm (see figures 2 and 3 for the illustration of this).

The input frequency will be derived from an unbuffered voltage controlled oscillator (VCO) source. If this source produces a fixed power level of 0dBm over the frequency band of interest (see section 2.3) and the first pre-amplifier (VCO buffer) stage has a gain of 7dB, then three subsequent pre-amplifiers each with a gain of 10dB could be used. The devices chosen for these stages must have a maximum power rating that enables the peak output power condition to be achieved; this is illustrated clearly in figure 4.

Power level control can be achieved either by using an adjustable gain MMIC in the second pre-amplifier stage, or by using a reflective PIN diode attenuator. The use of a dedicated variable gain MMIC to provide adjustable power control is illustrated in figure 4. A typical variable gain MMIC should be able to provide a linear gain variation of about 15dB. To increase this range, the device may be biased to operate in its non-linear region. This would require a look up table or a software function to convert the low-level input power demand to a representative bias voltage. The difficulty with operating in this region is the lack of device-to-device repeatability, which could prove to be a problem at a later stage when multiple systems are developed. In this case each system would require individual tuning, which is a costly process. The possible

dynamic range available would still be limited to around 30dB, hence this method of controlling the power will be considered as a second option.

Since it is required to match the instrument into the tissue load at a power level as low as 0dBm; this cordially imposes the constraint that the minimum system dynamic range is 49dB. This would be impossible to achieve using a single variable gain MMIC, therefore a better approach is to use a reflective PIN diode attenuator, as illustrated in figure 5. It is envisaged that a 50dB PIN diode attenuator could be used in this design, thus providing a power variation at the output of the amplifier of between: –1dBm and 49dBm. Unless a PIN diode unit is used that contains an analogue lineariser, the voltage to the PIN diode will still require conditioning (anti-log function or via look up tables), but device variation should be minimal, thus tuning of individual systems should no longer be required.

**2.3. Frequency Source with Provision for Fine Adjustment** – As briefly mentioned in the last section, the frequency source will be a voltage-controlled oscillator (VCO), whose frequency can be adjusted between 14GHz and 14.5GHz. The unbuffered power required at the output is 0dBm, and this level should remain constant to within +/-0.05 dB over the frequency band. The fine frequency variation can be used as a secondary adjustment when maximum power is demanded from the system, i.e. there will be a specific frequency in the band whereby circuit resonances occur and maximum power can be achieved. It is also possible to sweep the frequency over the band to provide some instrument tuning, i.e. increase the frequency where instrument is slightly too short for resonance and vice versa. Where the frequency has already been adjusted for maximum power output, a compromise between this frequency and that found for instrument tuning has to be found. The VCO and the control monitoring signals (foA and foM respectively) are shown in figures 4,5 and 7). It is intended that the microwave circuit elements described thus far in sections 2.1, 2.2 and 2.3 will be combined and layed-out together on one microstrip circuit board using a microwave layout package such as LIBRA [2], hence making the design of the microwave assembly as compact as possible.

**2.4. Triple-Stub Static/Dynamic Tuning Network and Output Isolator** – This unit will consist of an air filled cylindrical waveguide (split into two isolated sections), with two short-circuit ends, two N-type flange mount connectors with E-field probes connected, and three tuning elements placed either 1/8 or 1/4 of a wavelength apart; the construction is illustrated in figure 6.

Essentially, the unit will be made up from two cylinders, one inside the other, with the ends closed but removable to facilitate the setting up and adjustment of the E-field probes (instruments, electrodes, antennas). The cylinders are isolated from one another in terms of DC using either Kapton tape or a thin sheet of other low loss, high voltage breakdown dielectric material, i.e. PTFE or polypropylene, to provide an electrical isolation barrier between the generator and the patient circuit of up to 6KV. The frequencies of interest will pass through the waveguide unattenuated with an insertion loss of <0.1dB. The two cylinders with the insulation material in-between slide together, and are a tight (not interference) fit. The mean diameter is such that the waveguide supports the dominant mode of wave propagation for a cylindrical waveguide at frequencies between 14GHz and 14.5GHz. The isolator is a reciprocal device and the input/output signals (output from the power amplifier and generator

front panel connector respectively) are connected using two E -field probes connected axially a quarter wavelength from each of the closed (shorted) ends of the waveguide. The length of the probes will be about a half the internal diameter of the cylinder. The diameter of the probes should be such that they can handle a level of CW power of up to 46dBm (about half maximum power available at the front end of the generator); they may be manufactured from either: copper, brass or silver. Their ends should be rounded to help to prevent voltage breakdown. The E-field probes are connected to female bulkhead N-type connectors to enable co-axial connection to and from the unit. The distance between the centres of the two probes should be a multiple of half wavelength at the frequency where peak power is generated. Three M3 screws (or rods) will be placed axially at an eighth or a quarter of a wavelength apart, and a quarter wavelength from the center of one of the E-field launch probes. The length of the screws (or rods) are such that they just touch the opposite wall of the waveguide when fully adjusted. The adjustment enables the instrument to be matched into the impedance of the tissue (or other) load, i.e. enables an excursion to all valid regions of the Smith Chart. Initially, the system is to be set up to enable only manual tuning to be implemented only, but provision will be made for this to be automated by using servo controlled motors (or other electromechanical actuators), such as Turfenol D [12], for tuning screw (or rod) adjustments. The adjustments will be made according to feedback information from reflected power monitors and temperature probes inserted either at the end of the instrument, or perhaps via field/temperature probes buried at a remote site inside the tissue. Initially, it is envisaged that the sensors will be in the amplifier and the instrument. Figure 6 shows an embodiment for the isolator and tuning unit and figure 7, gives the preferred embodiment of the complete microwave assembly. Power budget details are given, together with phase information for splitter/combiner configurations. The numbers given in figure 7 assume zero component and track insertion losses, hence they are rather on the optimistic side. The PIN diode attenuator will be chosen to vary the gain since it provides the large dynamic range required to enable power matching into tissue to take place at power levels as low as 0dBm (see section 2.2), and the 3dB, 90 degree couplers have been chosen because this arrangement allows for individual amplifiers to go down whilst not effecting the operation of the other power amplifiers, due to the fact that any reflected energy from the dysfunctional stage is dumped into the 50Ω resistor connected to the isolated ports of the couplers (see sections 2.1 and 2.2).

**2.5. Microprocessor/Peripherals and User Interface** – A 32 bit microprocessor and associated peripherals will be used, together with a 3-line LED display and a dedicated keypad, to control the system and to provide a user friendly interface between the user and the system. The system will be initially set up by the user (surgeon or operator), via the keypad and display, to provide the desired power level for a predetermined duration. Either a footswitch pedal or a switch located on the instrument will then be activated to enable the power to be applied to the tissue. It will be possible to operate the system in continuous mode, whereby once the power level is set by the user, it can be delivered continuously on demand, i.e. the level will be unaffected by feedback information.

It is envisaged that there will also be an engineering mode, which will only be accessible to system engineers and technicians. This mode will be used to make hardware system adjustments and implement software changes.

In terms of the control aspects of the system, the microprocessor is responsible for monitoring or making adjustments to the following signals: DC Power supply, Forward and Reverse power levels, Temperature information, Frequency adjust/monitor, Power level adjustment (via gain control), Automated Triple-Stub tuner adjustment and Instrument Identification . The pertinent signals from the above group are addressed in detail as follows:

2.5.1 DC Power Supply – These are all input signals to the microprocessor: The drain voltage (designated: VDDp) for the four GaAs FETs used in the main output power stage, the gate-source bias voltage (designated: Vgsb) for all of the GaAS FETs used in the design, and a general purpose supply voltage (designated: Vgp) for all other components (microprocessor, etc.) are sampled and read into the microprocessor. Should any of these voltage levels be unavailable, or fall outside an acceptable window, then the system will automatically shutdown and a system error will be flagged up on the user display. The gate-source bias voltage (vgsb) is monitored continuously since its failure will cause the output of the power amplifier to go to its maximum level and damage could be caused to the final stage power amplifier transistors.

2.5.2 Forward and Reverse power levels – These are also all input signals to the microprocessor and are provided from diode detector units connected to monitoring ports of edge-coupled microstrip directional couplers (or other manifestations); the signals read are: Pfa – Forward power at output of the power amplifier, Pra – Reflected (reverse) power level coming back to the output of the power amplifier, Pfi – Forward power at the instrument, and Pri – Reflected (reverse) power going back into the instrument. This information enables the demanded power level and load matching be adjusted under dynamic loop control .

2.5.3 Temperature information - This information is fed into the microprocessor via thermocouples followed by some analogue pre-processing; the signals are: φA – Power amplifier output stage temperature, φI – Instrument temperature, and φT – Tissue temperature. If φA or φI are above a set threshold, then the power will be backed off or the system will shut down. The output power level will also be adjusted according to φT. At a later date, when all initial system developments have been carried out, this information will be used in order to help perform automated dynamic tuning adjustments.

2.5.4 Frequency – There will be provision to monitor the frequency from the VCO via the frequency monitor signal (foM) and to adjust the output frequency using a low frequency signal (foA), provided by the microprocessor. The frequency will be adjusted to provide fine tune for maximum power amplifier output level, as well as some instrument length compensation (see section 2.3).

2.5.5 Power – This signal (Ga-p) is a low frequency signal provided by the microprocessor to control either the gain of the second pre-amplifier or the level of attenuation controlled by a reflective PIN diode attenuator. A conditioned bias, or drive, voltage is required at the input to enable a linear adjustment of power to be made over the range of between 0dBm (1mW) and 49dBm (80W). It is envisaged that a voltage of between 0V and 4.8V will be made available from the microprocessor to control the amplifier/attenuator.

2.5.6 Stub tuning – In the fully automated system there will be three signals (MpA1, MpA2 and MpA3) provided by the microprocessor to adjust, via servo driven stepper

motors (or other electromechanical actuators), the three tuning stubs. Adjustment will be made according to information provided by the user demanded power level, the forward and reverse power levels and the temperature information yielded from φT (see sections 2.1, 2.4 and 2.5.3).

2.5.7 Instrument Identification – This will be a signal sent from the instrument into the microprocessor to identify the instrument being used and to set the generator software accordingly. An infrared (IR) link could be used, whereby the instrument transmits a signal (TXID), which is received by a detector (RXID) built into the generator. The block diagram given in figure 1 indicated each of the above mentioned signals.

**2.6. Instrument Identification Circuit** – Each instrument used is specific to the treatment being carried out by the surgeon, therefore, to enable the correct default power settings, or perhaps for specific procedure dependent software to be loaded, the generator must be told which instrument is connected. This can be achieved using a small low frequency IR transmitter located in the instrument and a receiver at the generator end. A simple coding scheme can be used, and initially codes for 100 instrument types will be put in place. The transmitter will only be activated when the instrument is connected to the cable assembly and the microprocessor will not read information when the generator is delivering UHF power. Once the instrument has been recognised by the microprocessor, the display will indicate the type and provide some basic procedural information. The microprocessor signal must be in receipt of the identification signal before the power amplifier supply (VDDp) voltage comes up. It may be possible that the power supply to power-up the IR transmitter could be derived by rectifying a low level UHF signal available to the instrument, i.e. 20dBm (100m would be sufficient.

**2.7. DC Power Supply** – This can be a switch mode power supply (SMPS) that provides the following three voltages: 12V(up to 33A) which is the drain supply voltage (VDDp) for the power GaAs FET transistors, -5V to –2V (<10mA) which is the gate-source bias voltage (Vgsb) for the GaAs FETs (it may be required to derive multiple biases from a single source, dependent upon MMICs used), 5V [or 3.3V] (up to 4A) which is the power supply voltage to the microprocessor/peripherals, the three-line display, the power supply for the first four pre-amplifiers, the power supply for the operational amplifiers used in the detector and temperature sensing circuits, and the power supply for the VCO (this voltage is designated: Vgp).

An internal circuit is also required to ensure that the negative bias voltage (Vgsb) is at an acceptable level to pinch off the channels of the *GaAS* FET power devices before the main drain supply voltage (VDDp) comes up, and on system shutdown, VDDp is switched off and fully discharged before Vgsb is removed. Also, should, for any reason, the negative bias go down, then the drain supply will immediately follow. The SMPS should be capable of delivering output power of up to 500W.

**2.8. Generator-to-Instrument Cable Assembly** – The interconnection between the output of the generator and the instrument will be made using either a length flexible waveguide or low loss co-axial cable. The insertion loss of the complete assembly must be less than 1dB per meter and it should be terminated at both ends with N-type, female connectors, whose insertion loss is less than 0.1dB (for small

instruments, SMA or miniature co-axial connectors may be considered for the instrument end). The length of the cable will be between 1m and 3m. The actual length used is dependent upon treatment procedure and the maximum power level required at the end of the instrument (distal end). For portable applications where the generator may be contained in a back-pack, for example, a 1m length would suffice. It may be noted from transmission line theory that if the cable impedance is not 50Ω, but the cable length is an exact multiple of half the guided wavelength at the specific frequency of the VCO, then the impedance seen at the source (the generator) will be the same as that of the load (instrument in contact with tissue). Therefore, the cable becomes effectively transparent, except for a loss factor proportional to twice its length. This could be used in producing geometrically and ergonomically favorable interconnections, which is extremely important for precision work, where small, lightweight cables are essential.

Suitable co-axial cable assemblies which have been identified so far use low density PFFE dielectric and have a copper center conductor. Three possible suppliers are: Reynolds[4], Utiflex[5], and Huber & Suhner[6]. The flexible waveguide is heavier and is not as flexible as co-axial cable. Therefore, it is only considered for use with the larger waveguide instruments, where large aperture sizes are necessary, and instrument maneuverability during treatment is not an important factor. The insertion loss at this frequency for flexible waveguide is normally marginally less than that for the co-axial cable. A possible supplier for flexible waveguide is Flann Microwave [7].

In the initial development work it is envisaged that the impedance of the cable, including that of the connectors, will be 50Ω, but this may be modified later to overcome physical constraints, as mentioned above. A low impedance source may favorable since it would keep the voltage levels down and provide a better match into low impedance tissue structures. This would be particularly effective for matching into blood, which could be very important in open-heart surgical procedures.

**2.9. Micro-Miniature Co-axial Instrument Group** – These micro-miniature instruments will be co-axial structures where it's possible to achieve an overall outside diameter of less than 1mm. Thus making it feasible to carry out very intricate precision treatment on delicate organs, such as the brain and throat, where it is paramount that the energy source does not affect surrounding tissue. Such instruments may also be used in open-heart surgical procedures where fast coagulation would be very useful. Although this is outside of the scope of the work documented here, It should still be noted here that such instruments could be used as an aid in general surgery where lower acceptable Industrial Scientific Medical (ISM) frequencies, such as 5GHz and 2.5GHz, could be adopted.

The general instrument structure is shown in figure 8, where it can be seen to consist of a center conductor and an outer return conductor, made from either copper or silver, with a low loss dielectric material separating the two. The characteristic impedance of the structure is determined by the ratio of the inner diameter of the outer conductor to the outer diameter of the inner conductor and the permittivity of the dielectric material. The structures to be considered initially in this work will have an impedance of 50Ω, but other more geometrically manageable impedances may be chosen where either quarter wavelength transformers are used or the length of the structures are exact multiples of half wavelength at the frequency of operation (see

section 2.8). The dielectric material used must have a be very low loss factor (low $\tan\partial$) at frequencies in the range: 14GHz to 14.5GHz in order to minimise electrode heating and insertion loss through the instrument. If the magnitude of sheath current, which flows along the outer conductor, is high enough to be felt by the user, then a number of quarter wavelength short-circuit to open-circuit baluns can be placed along the outer conductor, as shown in figure 8. These sheath currents can cause burns and so they should be prevented at all cost. If impedance transformations are required at the instrument end, then this can be easily realised using quarter wavelength co-axial sections of suitable impedance. The connectors can either be N-type or SMA (SMB or SMC may also be considered). For input power levels of 46dBm (40W) or greater N-type should be used. Other terminations may need to be considered for very small diameter instruments. Several semi rigid-cables with diameters that gradually reduce could also be considered, or, perhaps, the recently introduced miniature microwave connector set may be a solution for low power levels. Very small co-axial structures allow only a pure TEM wave to propagate even at the high frequencies used here since the diameters considered are much less than half the guided wavelength.

One very interesting application of these instruments is to enable treatment of cancerous cells at a very early stage via keyhole surgery. In this case the outer diameter of the instrument will be less than 1mm (at powers of less than 5W, semi-rigid cables with an outside diameter of0.3mm are available) . It may be possible to terminate the end of the instrument with a pointed cone of high permittivity, low loss microwave ceramic material. This would concentrate the electric field distribution at the tip and allow fine tissue tunneling into the cancerous region. This construction would provide a very high energy density source that could be used to channel through an organ, i.e. the lung or breast, causing minimal damage. When the target are reached, the power level could be increased to enable the cancerous tissue to be eradicated via a short burst of very higher energy radiation. The dominant energy transport mechanism used to get the probe to the cancerous site and that used to destroy the cancerous cells would be radiation. The channel used to reach the cancerous site will be small enough such that the damage caused to healthy tissue heals quickly, causing the patient minimal stress. Figure 9 shows a possible construction for the instrument described here.

Larger diameter co-axial constructions can be considered, but it should be noted that when the diameter of the inside of the outer conductor becomes greater that a half wavelength of the EM wave, then other modes of propagation will occur which will provide constructive and destructive interference to the main signal, making it more difficult to control the tissue effect. However, if the modes could be launched in a controlled manner then this may lead to some interesting tissue effects in terms of the variation in depth of penetration due to the various E and H fields being radiated. There would also be a modal variation in power level. The study of the variation in depth of penetration into various tissue structures as a function of mode would be a very interesting phenomena to study. Hopefully, it will be possible to address this when the initial system development has been completed.

The most controlled method to launch other modes of propagation is by using waveguide structures; these are considered in the following section.

**2.10. Larger Waveguide Instrument Group** – The waveguide instruments will normally be used to treat cancerous growths that have already grown to a relatively

large volume before commencement of treatment. The growths may be secondary, in which case the treatment may only lengthen patient life expectancy by a short period of time.

The waveguide structures have no center conductor, and the geometry can be adapted to suit the location of the organ being treated as well as other surrounding organs. The usual geometries considered are rectangular and cylindrical, but others, such as square, ridged or elliptical, are possible. Large waveguide structures are suitable for procedures where instrument maneuverability is not an issue of prime importance.

The structures can be filled with a low loss microwave dielectric material (loaded), or can have an air filled cavity (unloaded). It is possible to use waveguides for smaller open-surgery sites or relatively large keyhole surgery applications. In these cases the cavity will be loaded with a high permittivity material in order to minimise the aperture size. Suitable microwave materials are available from Hiltek Microwave [8]. One such material is known as 'Shaefer' which is available with permittivities from between 4 and 22. This material has the advantage that it is very easy to machine. Microwave ceramics can have permittivities that go up to, and above, 100, but they can be difficult to machine and make experimental investigations rather difficult. Strontium Titinate (StTi) can have a permittivity of up to 200, but is extremely expensive.

For the initial instruments considered here, dominant mode operation will be used and the effects on tissue caused by launching more exotic modes will be addressed after an initial product has been fully developed. The EM field will be launched into the waveguide structure via an E-field probe placed a quarter wavelength from the shorted end wall of the waveguide, as illustrated in figure 10.

Energy settings and treatment time will be determined by the severity of the cancerous growth, i.e. its volume, and the characteristics of the surrounding organs. The energy density available is limited due to the large aperture sizes that are possible. Therefore, the time necessary for the tissue to reach the required temperature to ablate the cancerous growth will be longer (much longer than the thermal time constant of the tissue), hence the dominant energy transport mechanism is more likely to be conduction, as apposed to the high energy density miniature co-axial instrument case where it was radiation. These instruments will be tuned, either statically or dynamically, for the best impedance match into the tissue at the frequency range of operation to enable the most efficient energy transfer rate . Tuning will be carried out at low power levels, i.e. 0dBm to 10dBm (1mW to 10mW) using the triple-stub tuning network described in section 2.4 and shown in figure 6.

To make it possible to treat larger surface areas than that possible using a normal air filed cavity waveguide, modes other than the dominant mode will have to be considered. For example, $TE_{10}$ is the dominant mode for a rectangular waveguide, but if we decide to also propagate a $TE_{21}$ mode, then the aperature size will need to be increased by a factor of four. Figure 10 illustrates the normal loaded/unloaded rectangular and cylindrical waveguides, showing the dimensions for the dominant $TE_{10}$ mode and the $TE_{21}$ mode for a rectangular waveguide.

**2.11. Future Instrument Group** - We will briefly consider the possibility of the system being used for totally non-invasive cancer tissue treatment. It should be noted that this is very much a 'blue sky' venture and would be considered only after the initial product has been fully developed, and other more realistic ideas, such as the

development of very fine instruments and the system modification, to enable precision open-heart surgery to be performed, have been pursued.

*Let us now briefly consider the 'blue sky' idea:*

First of all, it would be necessary to split the energy source into *n* coherent sources, where *n* is a large enough number such that the energy impinging on the surface of the patient skin from one single source alone will have no effect on the tissue structure, i.e. a power level of 10dBm or less. If these individual sources are then arranged around the body and focused such that they converge to a spot of high energy at the location of the cancerous tissue, then there may be enough energy to affect the state of the tissue located in this area. Either the sources or the patient would have to be moved, with precision, to enable treatment of larger areas.

One of the main problems is that the source will be attenuated through air before reaching the patient surface. Also, there will be a reflection at the skin-air boundary, further loss through subsequent tissue layers and a reflection at each tissue interface encountered before the wave reaches its final destination. This implies that the individual signals will be greatly attenuated. Therefore, in order to make this idea at all feasible, a high magnitude source of energy would be required which would most likely be impractical. Another alternative is to consider using much higher frequencies, i.e. 100GHz or above, which may make it possible to focus the energy using lenses.

## 3. Claims:

This section lists a number of claims based mainly upon the proposed generator development, the two main instrument groups and possible applications thereof.

Future system developments are also listed, but it is envisaged that work will take place on these only after the initial system has been fully designed and developed.

A number of claims are also listed that are based on spin-off ideas which evolved when writing this document. These ideas fall into the overall realm of this work, but may not be related to the treatment of cancerous tissue. These have been listed both for completeness and to ensure their protection.

*Thus, the following claims are made:*

(i) A novel power amplifier will be developed and implemented that produces an output power of up to 80W (49dBm) over a frequency range of between 14GHz and 14.5GHz, using state of the art power *GaAs* FET solid state technology.

(ii) The microwave components: Frequency source, pre-amplifiers, power level controller, power splitter, power amplifiers, power combiner, measurement couplers and circulator/dump load,. will be all laid out on a low-loss microwave substrate to produce a compact design.

(iii) The solid-state solution yields a fine control of output power level and frequency. The PIN diode attenuator will provide a dynamic range of over 49dB.

(iv) Microstrip couplers at the output of the amplifier and at the instrument provide forward and reverse power information which is fed back to the microprocessor and used to dynamically control the system in a precise manner.

(v) The variable frequency source will provide a degree of secondary control for obtaining maximum power at the output of the amplifier by sweeping the frequency band until the power maximum is found. It also provides a method of tuning instruments for resonance,i.e. giving effective length adjustment.

(vi) A novel combined isolator and triple-stub tuning network using an air filled cylindrical waveguide cavity will be developed.

(vii) The isolator will enable the patient to be DC isolated from the generator to a level of up to 6kV.

(viii) The triple-stub tuning network will enable the instrument to be matched into the impedance of the tissue by applying a very low set-up power of between 0dBm and 10dBm prior to high power activation.

(ix)The triple-stub tuning network will enable the instrument to be tuned so that it does not radiate into air (poor match or low return loss). Again this will be carried out at very low output power level.

(x) Automatic adjustment of the triple-stub tuning network, via servo driven stepper motors (or other suitable electromechanical actuators) and a temperature sensor at the distal end of the electrode, will enable automatic tuning into tissue and power level adjustment according to the state of the tissue. It will also enable power mismatch when operated into air.

(xi) The fine power control and feedback information, coupled with the ability to slightly shift the source frequency, will help to provide enough information to enable the instruments to be efficiently impedance matched into the tissue being treated, enabling tissue ablation to be carried out with ease whilst preventing unnecessary thermal damage to surrounding tissue.

(xii) A low voltage switch mode power supply (SMPS) will be used for the system energy source. This helps make the system lightweight and portable.

(xiii) Using solid-state components to generate the UHF power and to adopt an integrated layout should, enable the system to be cost effective.

(xiv) The system will be portable, by virtue of size of the microwave compon (power amplifier GaAs transistors) and the SMPS, thus it could be used for outpatient surgery where regular treatment is necessary, i.e. for growth shrinkage.

(xv) The use of solid-state power GaAs FETs in medical applications such as those described in this document is unique.

(xvi) Micro-miniature co-axial instruments will be used which enable a controlled pure TEM field to be generated with no other constructive or destructive interference modes present.

(xvii) Micro-miniature co-axial instruments can be used to produce very high energy densities at the tip of the instrument .

(xviii) Micro-miniature co-axial instruments allow the energy to be focused and minimizes effects to surrounding healthy tissue.

(xix) Micro-miniature co-axial instruments allow precision procedures to be carried out on delicate organs, such as the brain, throat and the heart, using open surgery techniques.

(xx) Physically long micro-miniature co-axial instruments, constructed to have a very low insertion loss, can be used in minimal access surgery where ongoing treatment is necessary. In which case, the system could easily lend itself to outpatient surgery. This is augmented by (xiv).

(xxi) Slightly larger co-axial based instruments can support modes of EM field propagation other than the pure TEM mode. These may yield interesting tissue effects and it is proposed that they will be investigated at a later date. It has already been shown that for a rectangular waveguide, the $TE_{30}$ mode can be used to give a more

uniform tissue effect than that obtained by simply propagating the dominant $TE_{10}$ mode.

(xxii) All of the co-axial structures considered in this work will use fully enclosed copper/silver outer conductors and may also include BALUNS to minimise any sheath currents that flow back along the outer conductor. These instruments, therefore, present no risk to the patient or surgeon in terms of damage caused by un-focused radiation (or UHF burns).

(xxiii) The distal end of the micro-structure co-axial structures may be terminated with a very high permittivity microwave dielectric in order to concentrate the E- field in the region of the instrument tip, which is desirable for fast precise tissue tunneling and to help ensure that the dominant energy transport mechanism is radiation.

(xxiv) Waveguide instruments can be used which are loaded with microwave dielectric material in order to shrink their cross-sectional area (aperture). These structures have no center conductor and can support many useful modes of EM field propagation. In our initial work only the dominant modes will be considered, but the tissue effects due to other more exotic modes will hopefully be investigated later.

(xxv) Waveguide instruments can be used to treat large volume cancerous growths in vital organs of the body. The waveguide geometry is developed to suit the organ being treated as well as to minimise damage to other organs in the near vicinity.

(xxvi) Waveguide instruments can have various aperture sizes, which are dependent upon the wave impedance and the permittivity of the dielectric material used.

(xxvii) Due to the high UHF frequency used here, cylindrical waveguides loa with high permittivity material would be suitable for use in minimal access surgery (strontium titinate *stTi* has a permittivity of up to 200).

(xxviii) Waveguides can be tuned in the same way as the co-axial instruments using the triple-stub tuning network housed in the generator.

(xxix) Very large aperture waveguides may be constructed by launching modes other than the dominant mode.

(xxx) The waveguides developed here are all fully enclosed in an alluminium or brass housing, thus radiation will only be produced at the waveguide aperture. This minimises any possible radiation damage that could be caused to the patient or the surgeon during system activation.

(xxxi) Instrument identification will be implemented using an infrared transmitter located in the hand-piece, and a receiver located in the generator. Initially, it is proposed to use 100 unique codes to identify the various possible electrodes.

(xxxii) The system may be used for fully non-invasive treatment of cancerous growths if the main source of energy could be split up into many smaller coherent sources and then individually propagated with minimal loss, and focused for convergence to a single point source at the treatment site – this is a rather hypothetical application and quite unfeasible at this stage.

(xxxiii) A further application of the micro-miniature co-axial structures is where the cancerous growths form at inaccessible sites, such as the inside of a lung or breast. . In this case the use of a structure with an outside diameter of less than 1mm is envisaged, this will minimize the damage to healthy tissue on the way in; also by making a very small tunnel the patient recovery time is improved. A high permittivity

microwave ceramic cone could be used at the tip of the instrument to concentrate the E –field, thus speeding up the incision rate. The power (energy) will be initially set to enable tunneling to the treatment site to be dominantly caused by the radiation transport mechanism. Once the cancerous site has been located, the energy will be adjusted to enable the fast eradication of the cancerous cells. This again should be achieved using radiation as the dominant energy transport mechanism.

(xxxiv) A further application of the micro-miniature co-axial structures is in open-heart surgery, where very small and fine instruments that deliver energy at high UHF frequencies could be used to effectively cut and rapidly coagulate intricate tissue structures such as those found in the heart. The fast co-agulation would immediately prevent bleeding thus enhance possible precision available to the surgeon.

(xxxv) A UHF power source for the open-heart surgery application could be implemented using 5GHz or 2.5GHz UHF technology, where power devices and drive circuitry elements are more readily available at a lower cost.

(xxxvi) Where micro-miniature co-axial instruments are used whose outside diameters are less that 1mm, the energy density at the tip of the instrument may be so high that very small power levels, i.e. 5W, may be sufficient to cause the desired tissue effects. If this is the case then very lightweight cable assemblies can be considered which would be helpful when fine precision procedures are being carried out.

(xxxvii) The GaAs FET power transistors used for this work are also suitable to drive low impedance loads. One application considered is for switching magnetic fields and causing reversal of magnetization in a time frames of 15ps. A number of the devices could be combined using quarter wavelength transformers or 90° couplers to drive the fast switching fields into structures of very low impedance such as micros or stripline constructions.

(xxxviii) The use of such high frequencies (14GHz to 14.5GHz)enables high radiated energy levels with small wavelengths to be produced at the distal end of the instruments. This should help to ensure that the dominant energy transport mechanism for the micro-miniature co-axial structures is radiation, thus limiting damage caused by excessive thermal conduction.

(xxxix) A major application for such a system could be for the treatment of breast cancer. The therapeutic microwave energy will instantly ablate the lesion and leave surrounding tissue untouched. The micro-miniature co-axial structures aids probing to be carried out whilst causing minimal damage to healthy tissue.

(xxxx) If the return loss information, from the reflected power monitor located in the instrument, can be enhanced to such a level that all possible tissue types can be distinguished form one another, then the system could be used to locate as well as treat the cancerous growths. This probing could be possible at the early stage of the growths; it could also be used to ensure that the growth has been successfully destroyed at the end of the treatment. The probing may have to be carried out using a low power source that operates at a frequency where a resonance absorption peak occurring in the cancerous tissue can be discerned. This will mean sending two frequencies down the instrument, hence a signal combiner (filter) will be required.

(xxxxi) For fast dynamic adjustment of the triple-stub tuning network, rods may be used instead of screws and a magneto-strictive material, possibly Turfenol D [12], may be used for the actuators.

(xxxxii) For the micro-miniature co-axial instruments, $\lambda/4$ baluns could be constructed using low loss dielectric spray coatings (or thin tape, such as poliamide) combined with thin beryllium copper (or copper tape) in order to increase the overall diameter of the electrode. It may also be possible to recess the short-circuit to open-circuit balun into the outer wall of the semi-rigid body; leaving the overall electrode diameter unaltered. It should be noted that careful consideration would also have to be given to breakdown voltages and power levels launched into such small structures.

## 4. Concluding Remarks:

This document describes a novel design for a new electrosurgical system. It fully addresses the proposed development and implementation for a complete system capable of delivering UHF power, in a controlled manner, into cancerous tissue (especially soft tissue) in order to destroy (ablate) the cancerous cells and halt their multiplication, hence eliminate cancerous sites that manifest in vital organs of the human body. The development of the portable power generator, using state of the art solid state technology is initially addressed, along with the control, monitoring and the user interface aspects of the design. The proposed development for a range of electrodes (instruments) to be used to focus energy into the affected tissue is then discussed. In this section, consideration has been given to the fact that micro-miniature co-axial instruments should enable the dominant energy transport mechanism into tissue to be that of radiation. This is then compared with waveguide based instruments where the dominant transport mechanism is more likely to be conduction. Of course, in the case of waveguide instruments there is a mixture of radiation and conduction, but if the generator could deliver a high enough energy level, and the waveg instruments has a small enough aperture, then it should be possible to destroy the cancerous cells mainly by radiation. To achieve such small diameter instruments, it would be necessary to load the waveguide with a low loss microwave dielectric material that has a high permittivity. This material must be low-loss, otherwise the shaft would get very hot and could cause thermal damage to surrounding tissue, especially when used in minimal access surgery.

The major advantage of delivering instant energy into the tissue is that damage to the surrounding tissue can be minimized. The small co-axial structures should enable the treatment of very small lesions with a have a high level of control over the thermal profile produced; this would be particularly important if we were to consider brain tumor treatment. Also, healing times should be expediated through the minimization of collateral damage. This is particularly prevalent in the case of breast cancer treatment, where instruments with an outside diameter as low as 0.51mm will be considered.

With such small diameter instruments it may also be possible to probe the tissue and use the return loss measurement to provide information regarding the state of the cells. We may also be able to use this method to distinguish between healthy cells and those affected by cancerous growths.

A list of claims have been included in this document in order to identify the uniqueness of this work. It is hoped that it will be possible to file a patent based on this work sometime in the near future and that these claims will be used as the basis for the patent application.

It is intended to later extend the work presented here in order to allow the system to be used not only to treat, but also to locate the specific cancerous growths. The

regions where we envisage this to be possible are those of the breasts, the lungs and, possibly, the brain. This could make for a stand alone cancer location/treatment system, which may eliminate the need for imaging before treatment. Therefore, it may be possible to use the system for outpatient treatment, where treatment and monitoring is required at regular intervals. For this to be possible, it is envisaged that the directionality of the reflected power monitoring coupler (reverse return loss measurement) would need to be in excess of 20dB, the cable ripple would need to be fully characterized and taken into account, and enhanced timing mechanisms would need to be developed.

This system may also lend itself to treatments and therapies that are not concerned with cancerous growths; a separate document will address some of these. To enable the various novel instruments that have been conceived during this work to be considered in a more diligent manner, again a separate document will be written and a patent application generated/filed to ensure full protection of the designs.

## 5. List of Figures:

## 6. Abbreviations:

$V_{DDp}$ = Drain Voltage for four power GaAs FETS
$V_{gsb}$ = Gate-Source Bias Voltage for GaAs FETS
$V_{gp}$ = General purpose supply voltage
$Q_A$ = Amplifier Output temperature
$Q_I$ = Instrument Temperature
$Q_T$ = Tissue Temperature
$f_{oA}$ = Frequency Adjust
$f_{oM}$ = Frequency Monitor
$G_{a\text{-}p}$ = Gain Adjust for Power Control
$P_{fa}$ = Forward Power from Amplifier
$P_{ra}$ = Reverse (reflected) Power back to amplifier
$P_{fi}$ = Forward Power at instrument
$P_{ri}$ = Reflected Power Back into instrument
$M_{PA1}$ = Mechanical Power Adjust ($1^{st}$ Stub)
$M_{PA2}$ = Mechanical Power Adjust ($2^{nd}$ Stub)
$M_{PA3}$ = Mechanical Power Adjust ($3^{rd}$ Stub)
$S_{FA}$ = Switch signal for foot activation
$S_{HA}$ = Switch signal for hand activation
$T_{xID}$ = Transmit code for instrument ID
$R_{xID}$ = Receive code for instrument ID

PA = Power Amplifier

SMPS = Switch Mode Power Supply

FET = Field Effect transistor

GaAs = Gallium Arsenide

VCO = Voltage Controlled Oscillator

TEM = Transverse Electromagnetic

EM = Electromagnetic

BALUN = Balanced-to-unbalanced (transformer)

UHF = Ultra High Frequency

DC = Direct Current

MMIC = Miniature Microwave Integrated Circuit

dB = Decibels

dBm = Decibels referenced to 1 milliwatt

mW = Milliwatt

GHz = Gigahertz ($10^9$ Hertz)

YIG = Yittrium Iron Garnet

PTFE = Polytetraflouroethylene

E = Electric field (V/m)

LED = Light Emitting Diode

SMA = Sub Miniature Assembly

H = Magnetic field (A/m)

Q = Quality factor (energy stored/energy dissipated)

IR = Infrared

ISM = Industrial Scientific Medical

CW = Continuous wave

## 7. Prior Art:

[pa1] Boston Scientific Corporation

http://www.bostonscientific.com

*abstract:* Boston Scientific has a division called Medi-tech, which is a leading developer of medical technologies used by the interventional radiologist, surgical oncologist and both general and vascular surgeons.

[pa2] Radio Therapeutics Corporation (RTC)

http://www.radiotherapeutics.com/coaccess.shtml

Radio Therapeutics Corporation (RTC) develop and manufacture radio-frequency based therapeutic devices in the field of internentional oncology for the ablation of various forms of soft tissue tumours.

On November 8th 2001, Boston Scientific Corporation announced the signing of a definitive agreement to acquire RTC. Boston Scientific had already set up a distribution agreement with RTC in USA and Japan.

[pa3] Microsulis 9.2 GHz Magnetron Based System

http://www.microsulis.com/news12.htm

*abstract:* Microsulis were awarded a large EPSRC grant in May 2001 to look into the treatment of secondary liver cancer using their already established 9.2GHz magnetron based system

[pa4] Celsion

http://www.celsion.com/breastcancertrials.htm

*abstract:* Chemotherapy and radiation therapy cannot always completely kill all breast cancers.

[pa5] Anderson Cancer Centre

http://www.mdanderson.org/~conquest/spring1998/froutli.com

*abstract:* Radiofrequency ablation surpasses cryoblation.

[pa6] Anderson Cancer Centre

http://www3.manderson.org/~oncolog/radiofrequency.html

*abstract:* promising radiofrequency treatment on unresectable (inoperable) liver tumours.

[pa7] D. Hung, et.al., 'Methods and systems for treating breast tissue,'
United States patent application number: 20020133151

Kind code: A1

Date: September 19th, 2002

Serial number: 144853

Series code: 10

Filed: May 15th, 2002

International class: A61B 018/18

[pa8] V.I. Chornenky, et.al., 'Hyperthermia radiation apparatus and method for treatment of malignant tumours,'

United States patent application number: 20020072645

Kind code: A1

Date: June 13th, 2002

Serial number: 731925

Series code: 09

Filed: December 8th, 2000

U.S. Current class: 600/3

U.S. Class of publication: 600/3

International class: A61N 005/00

[pa9] M. Dinesh, et.al., 'Tissue ablation with sliding ablation Instrument and method,'

United States patent application number: 20020087151

Kind code: A1

Date: July 4th, 2002

Serial number: 751472

Series code: 09

Filed: December 29th, 2000

U.S. Current class: 606/15, 606/33, 606/41

U.S. Class of publication: 606/15, 606/33, 606/41

International class: A61B 018/18, A61B 018/24, A61B 018/14

[pa10] A.G. Dickey, et.al., 'Method for selective thermal ablation,'

United States patent application number: 20010020178

Kind code: A1

Date: September 6th, 2001

Serial number: 746542

Series code: 09

Filed: December 18th, 2000

U.S. Current class: 607/101

U.S. Class of publication: 607/101

International class: A61F 002/00

## 8. References:

[1] Toshiba Semiconductors

http://www3.toshiba.co.jp/sic/micro/index.htm

[2] LIBRA

http://www.mwoffice.com/products/mwoffice.html

*also for a free trial:*

http://www.mwoffice.com/freetrial/index.html

[3] ACADEMY

http://www.contact.tm.agilant.com/tmo/eesof/support/

[4] Reynolds

http://www.reynoldsindustries.ltd.uk/microwave/#Flexible

[5] Utiflex

http://www.micro-coax.com/utiflex-cableguide.htm

[6] Huber & Suhner

http://www.hubersuhner.inc/products/cables.htm

[7] Flann Microwave

http://www.flann.com/products/components/components.htm

[8] Hilltek Microwave

http://www.hiltek.co.uk/prod1.html

*see also:* .....prod2.html,......prod3.html,.....prod4.html

*Contact*: Mark Hawker (MD)

[9] Rogers Microwave

http://www.rogers-corp.com/mwu/litintb1.htm

[10] MCS Microwave Limited

*Contact:* Morris Sweetland (MD), M.SWEET@FSDial.co.uk

Units 1-2 Cherry Tree Offices, Stambridge Road, Essex SS4-2AF, UK

[11] Florida RF Labs Incorporated

http://www.floridarflabs.com/htmlsite/products.asp

[12] Magnetic materials research group

University of Hull, Hull, UK

*Contact:* Dr Rob Greenough (Head of group)

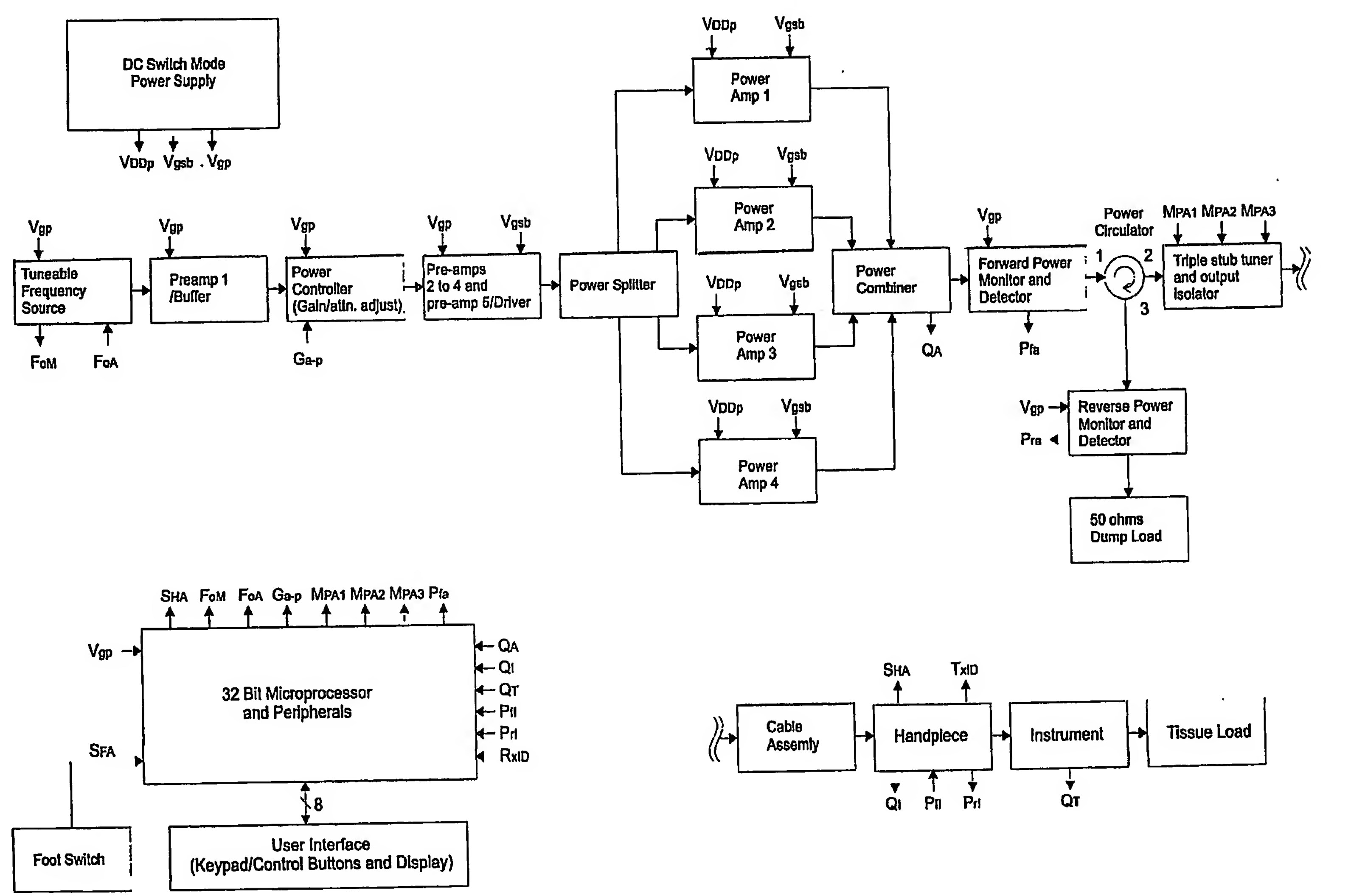
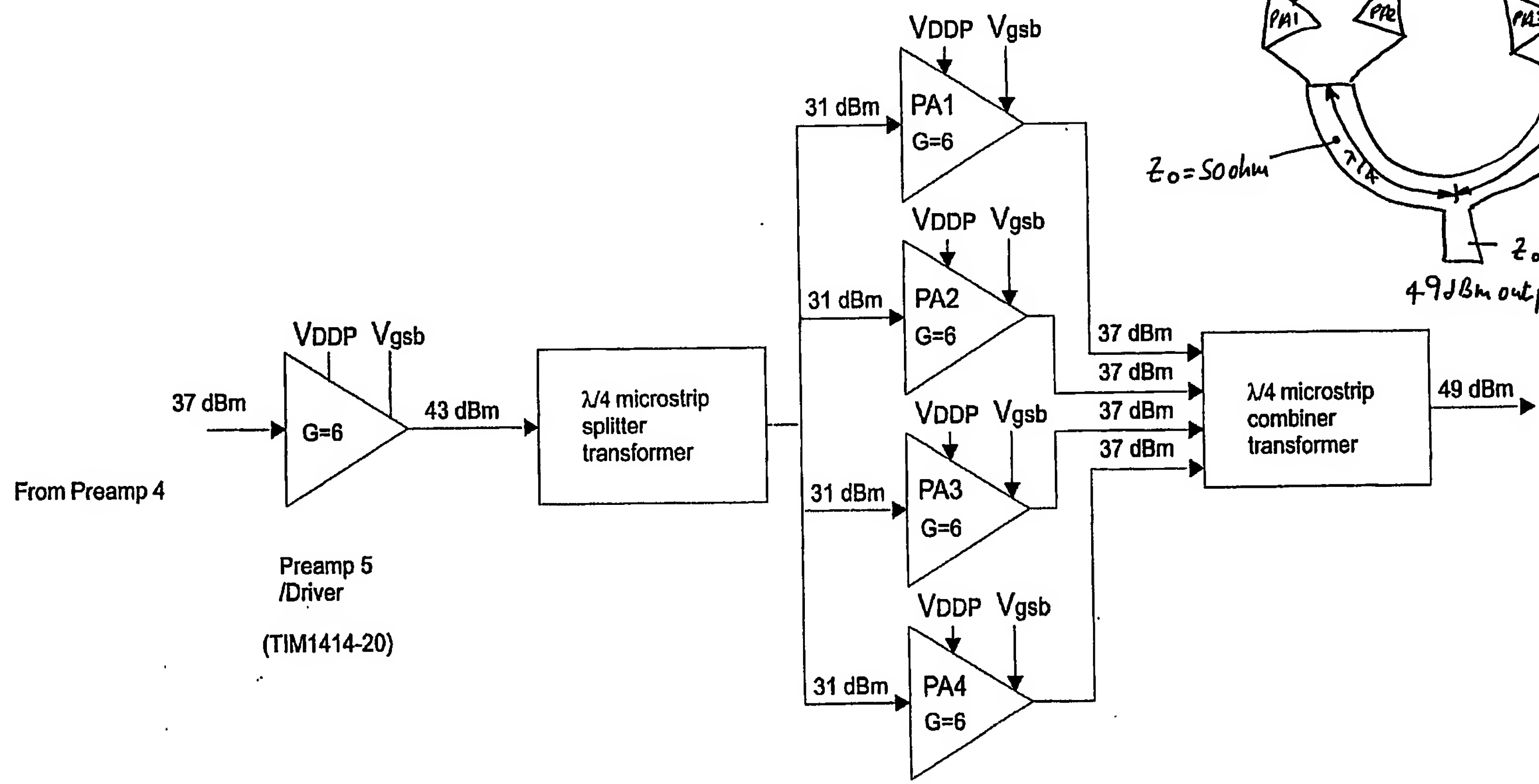



Figure1: System Block Diagram

Figure 2




also

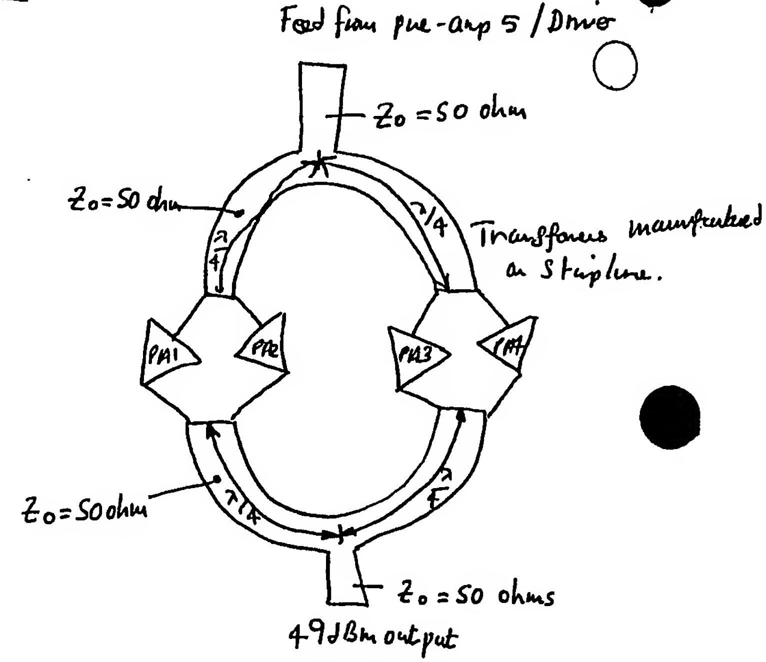


Figure 3

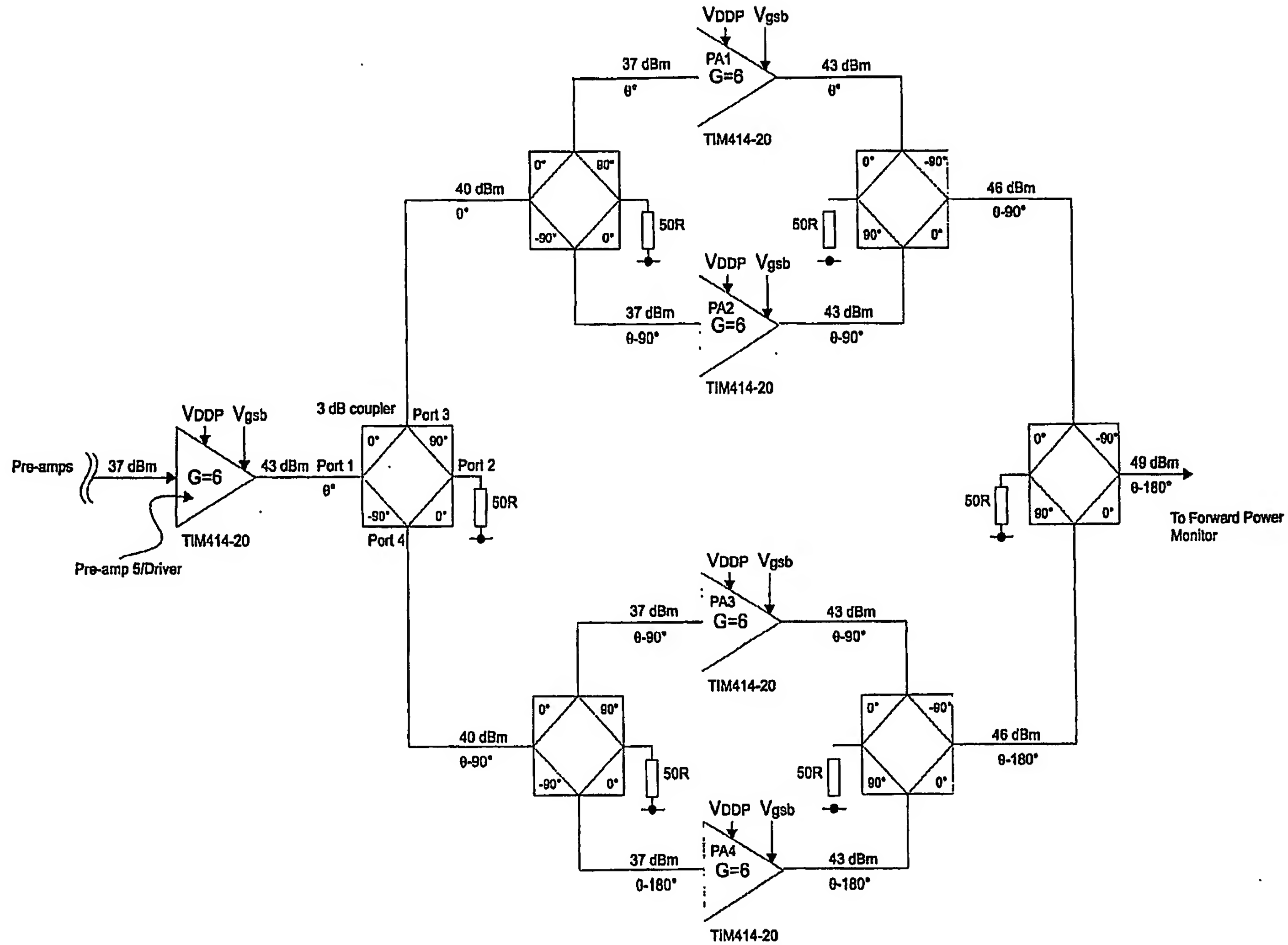
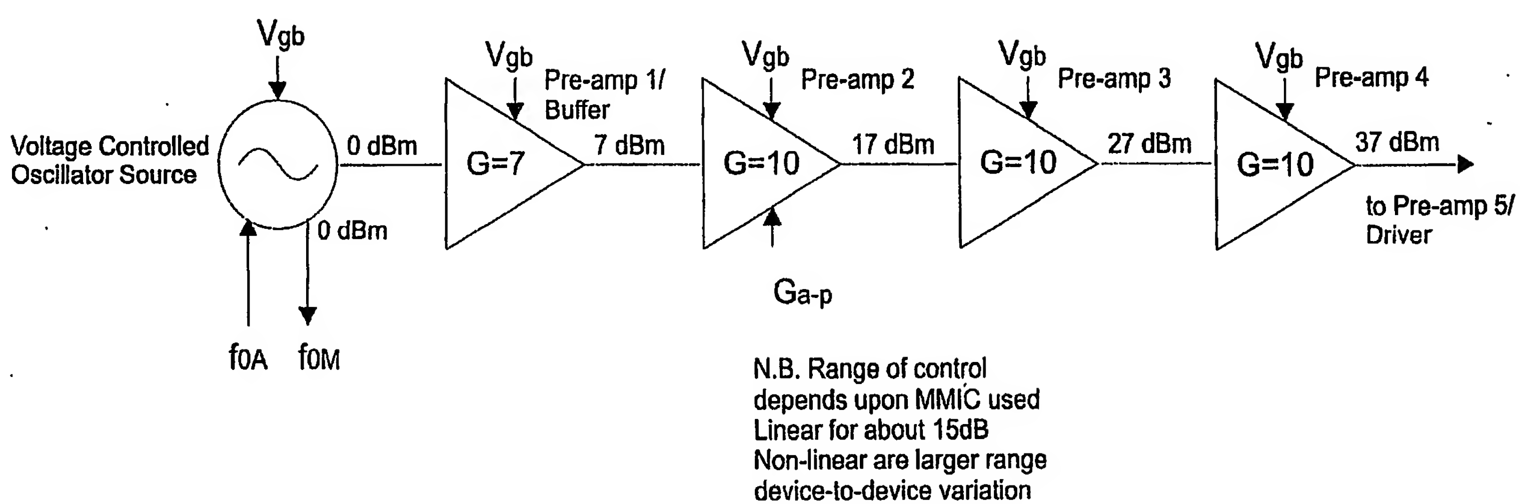
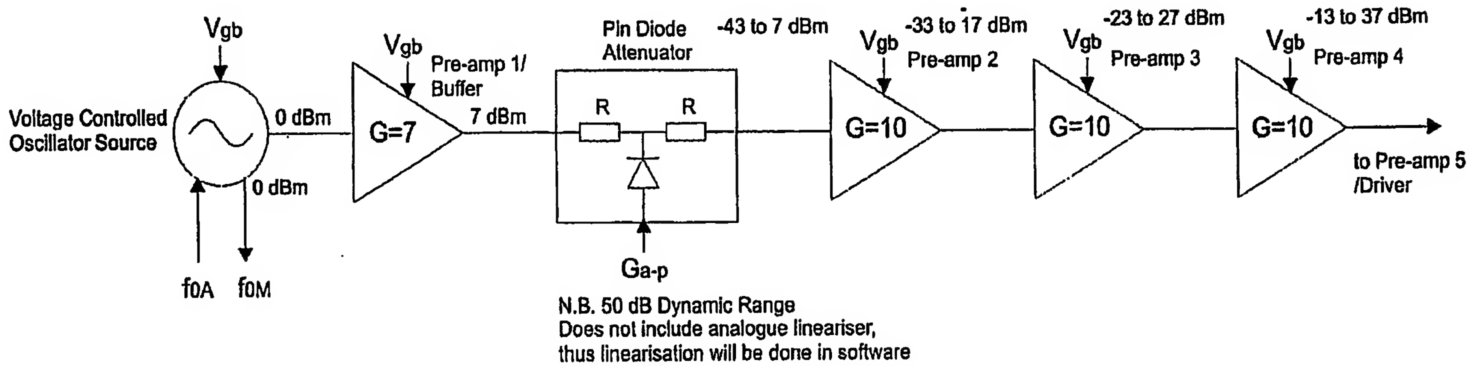

Pre-amps
37 dBm
VDDP Vgsb
G=6
TIM414-20
Pre-amp 5/Driver
43 dBm Port 1
θ°
3 dB coupler
Port 3
Port 2
Port 4
50R
40 dBm
0°
40 dBm
θ-90°
37 dBm
θ°
PA1
G=6
43 dBm
θ°
37 dBm
θ-90°
PA2
G=6
43 dBm
θ-90°
37 dBm
θ-90°
PA3
G=6
43 dBm
θ-90°
37 dBm
θ-180°
PA4
G=6
43 dBm
θ-180°
46 dBm
θ-90°
46 dBm
θ-180°
49 dBm
θ-180°
To Forward Power Monitor

Figure 4



Vgb
Voltage Controlled
Oscillator Source
0 dBm
0 dBm
f0A
f0M
Vgb
Pre-amp 1/
Buffer
G=7
7 dBm
Vgb
Pre-amp 2
G=10
Ga-p
17 dBm
Vgb
Pre-amp 3
G=10
27 dBm
Vgb
Pre-amp 4
G=10
37 dBm
to Pre-amp 5/
Driver
N.B. Range of control
depends upon MMIC used
Linear for about 15dB
Non-linear are larger range
device-to-device variation

Figure 5



Vgb
Voltage Controlled Oscillator Source
0 dBm
0 dBm
f0A
f0M
Vgb
G=7
Pre-amp 1/ Buffer
7 dBm
Pin Diode Attenuator
R
R
Ga-p
-43 to 7 dBm
Vgb
G=10
Pre-amp 2
-33 to 17 dBm
Vgb
G=10
Pre-amp 3
-23 to 27 dBm
Vgb
G=10
Pre-amp 4
-13 to 37 dBm
to Pre-amp 5 /Driver
N.B. 50 dB Dynamic Range
Does not include analogue lineariser,
thus linearisation will be done in software

Figure 6

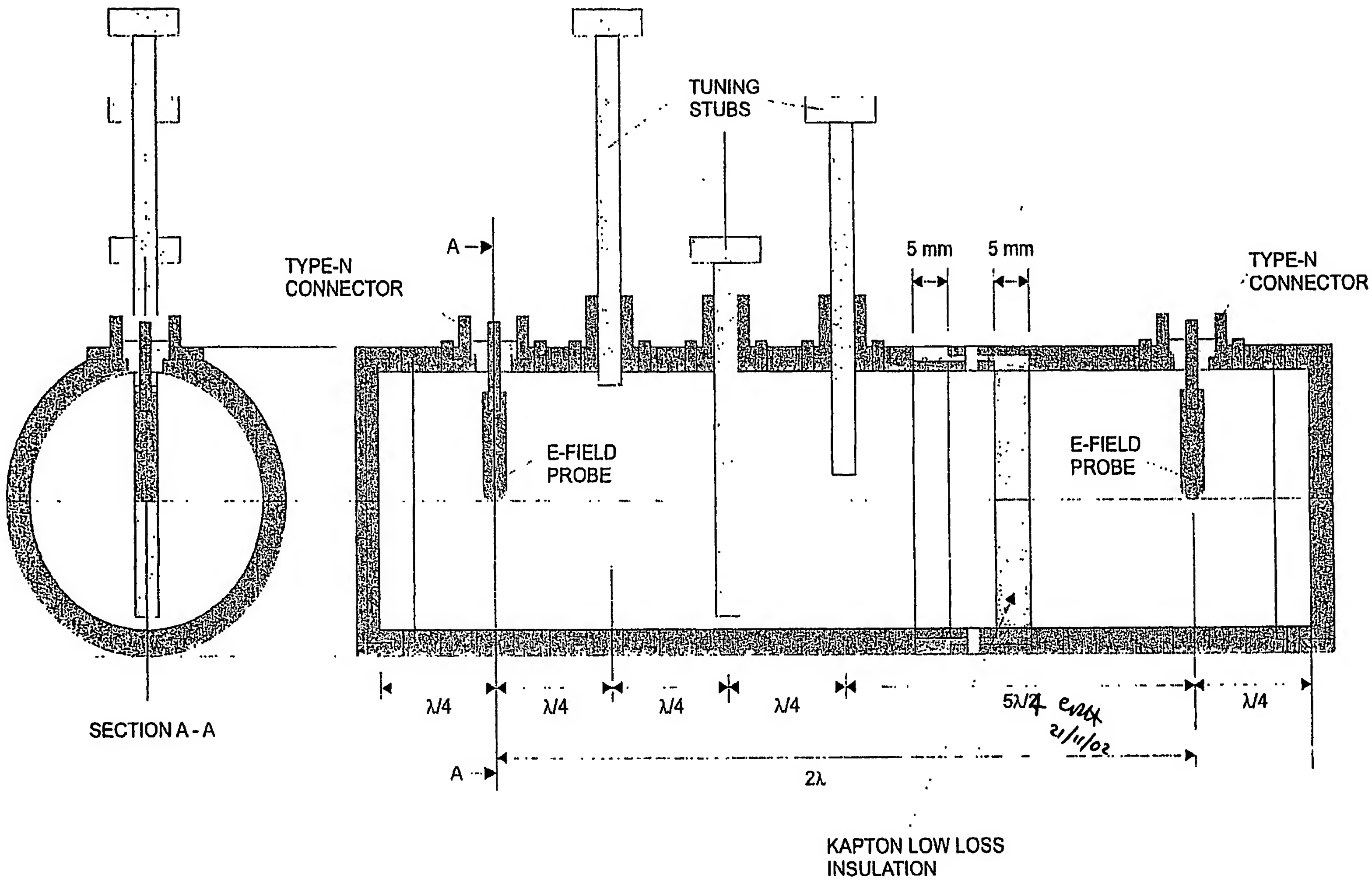

TUNING
STUBS
TYPE-N
CONNECTOR
TYPE-N
CONNECTOR
A
A
5 mm
5 mm
E-FIELD
PROBE
E-FIELD
PROBE
SECTION A - A
λ/4
λ/4
λ/4
λ/4
5λ/~~2~~4
λ/4
2λ
21/11/02
KAPTON LOW LOSS
INSULATION

Figure 7: Preferred Embodiment of Microwave Stages

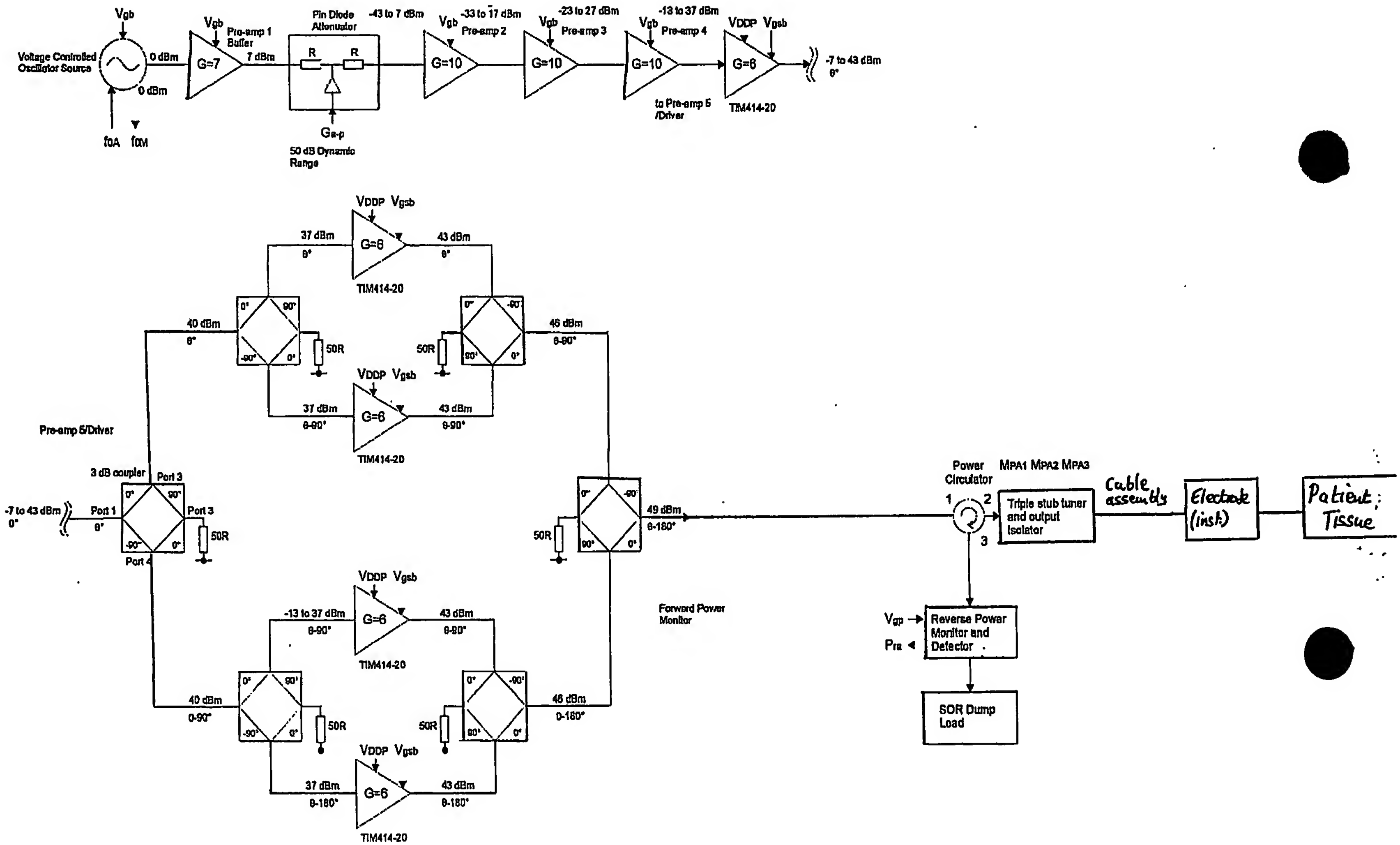
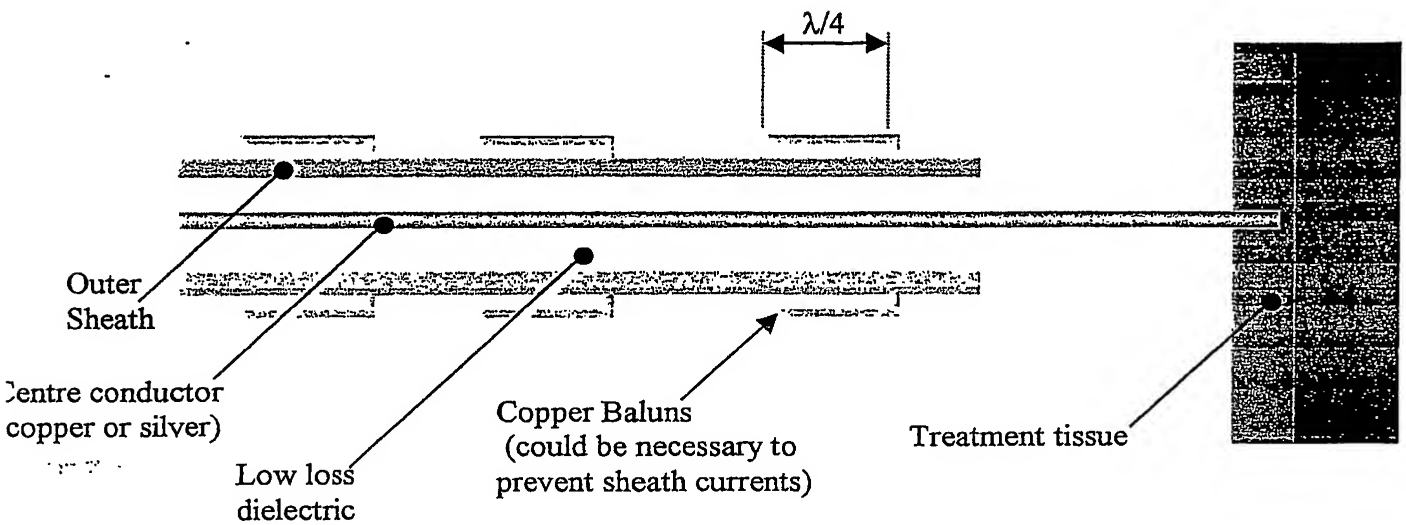
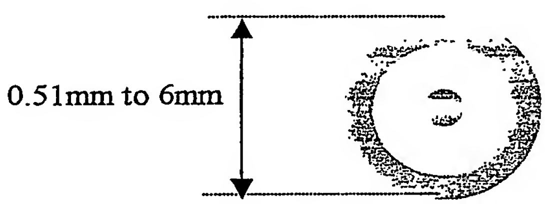


Figure 8: Micro-miniature co-axial instrument design:

Inside side cross-section:




Cross section:




Possible structures and end variants:

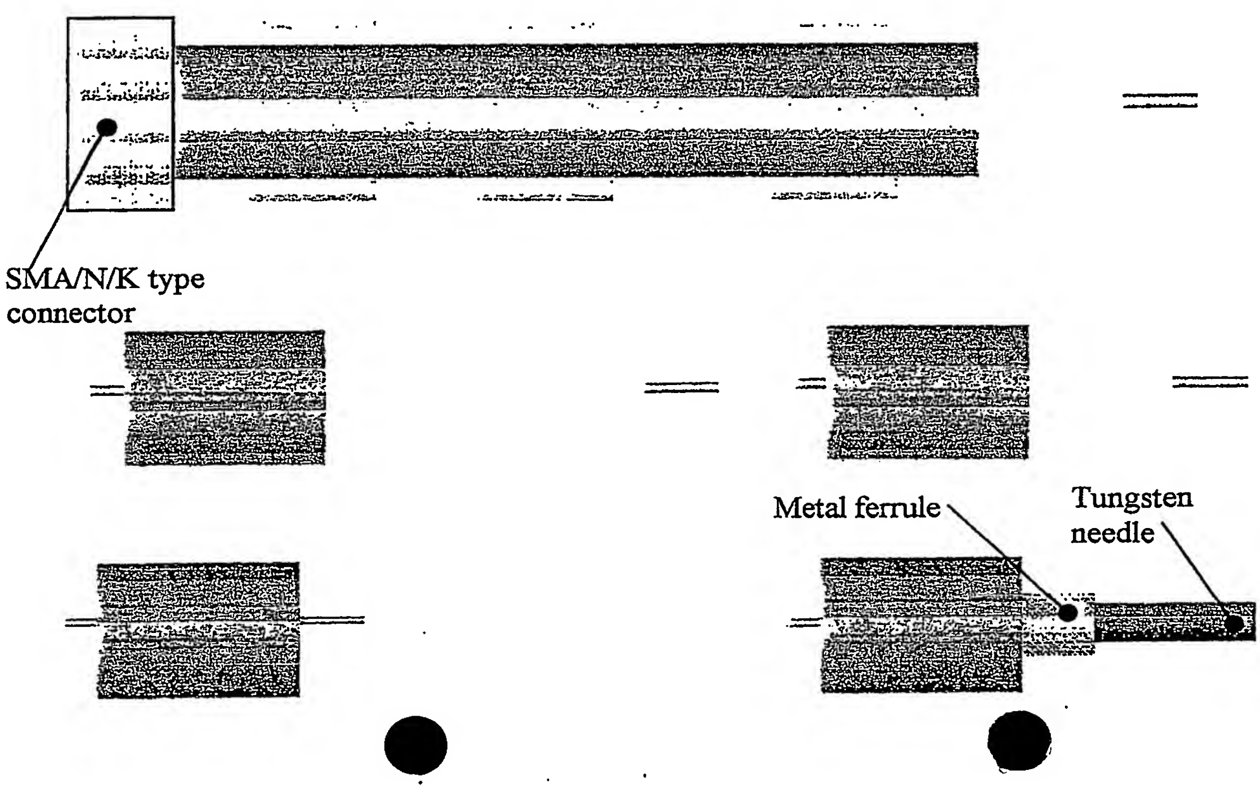
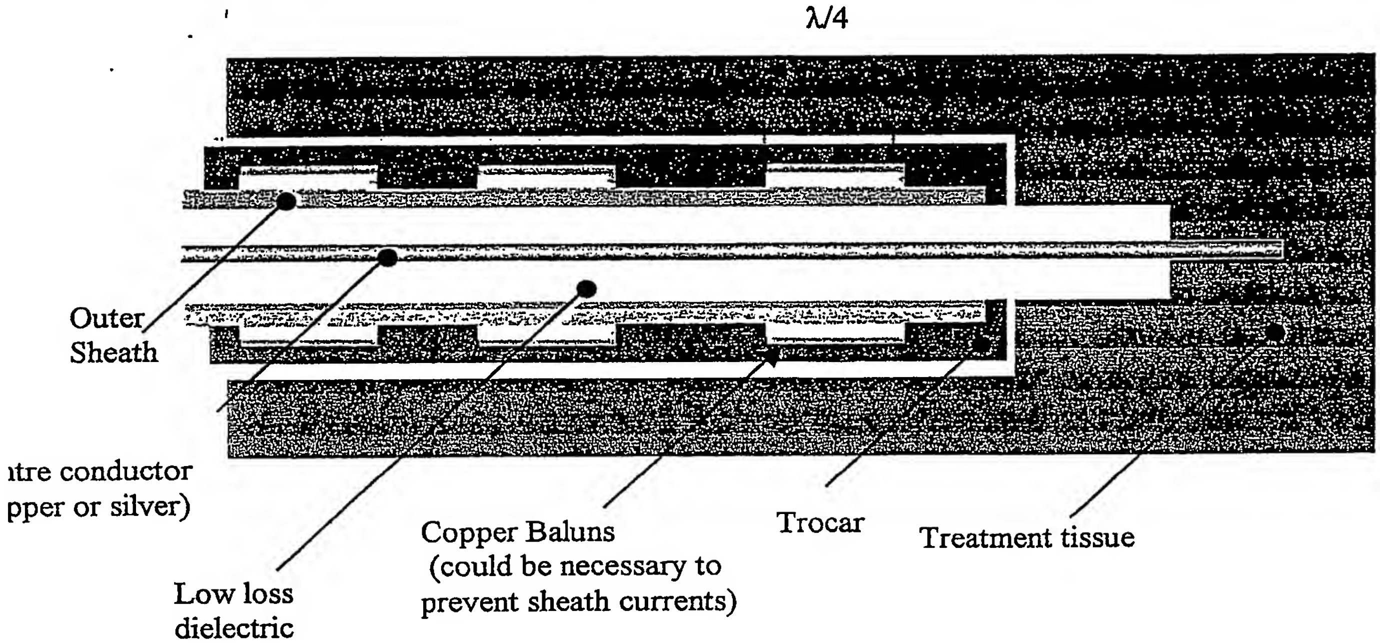
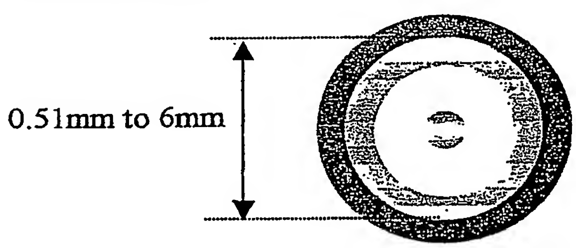


Figure 9: Keyhole treatment of small inaccessible sites using miniature co-axial instruments

Basic instrument:




Cross section:




Embodiment 1:

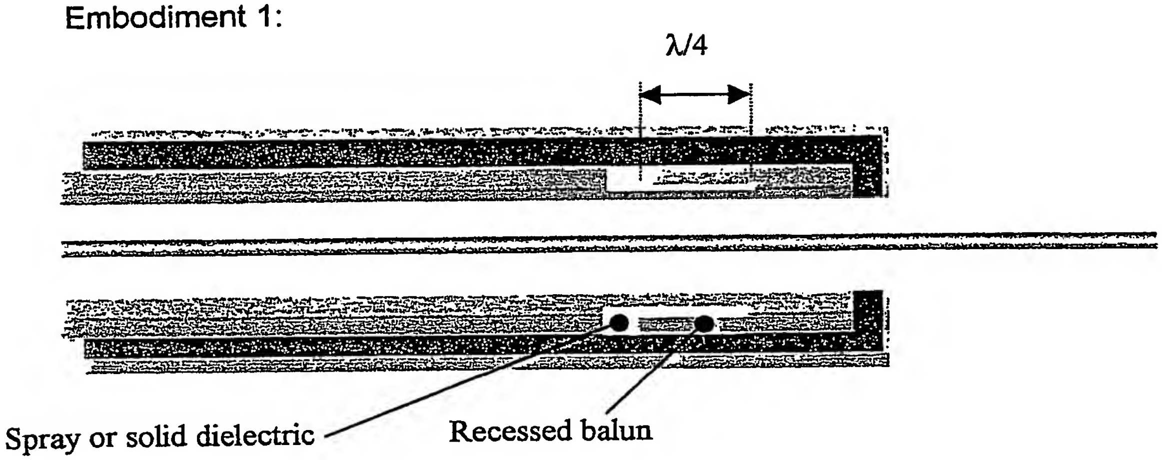
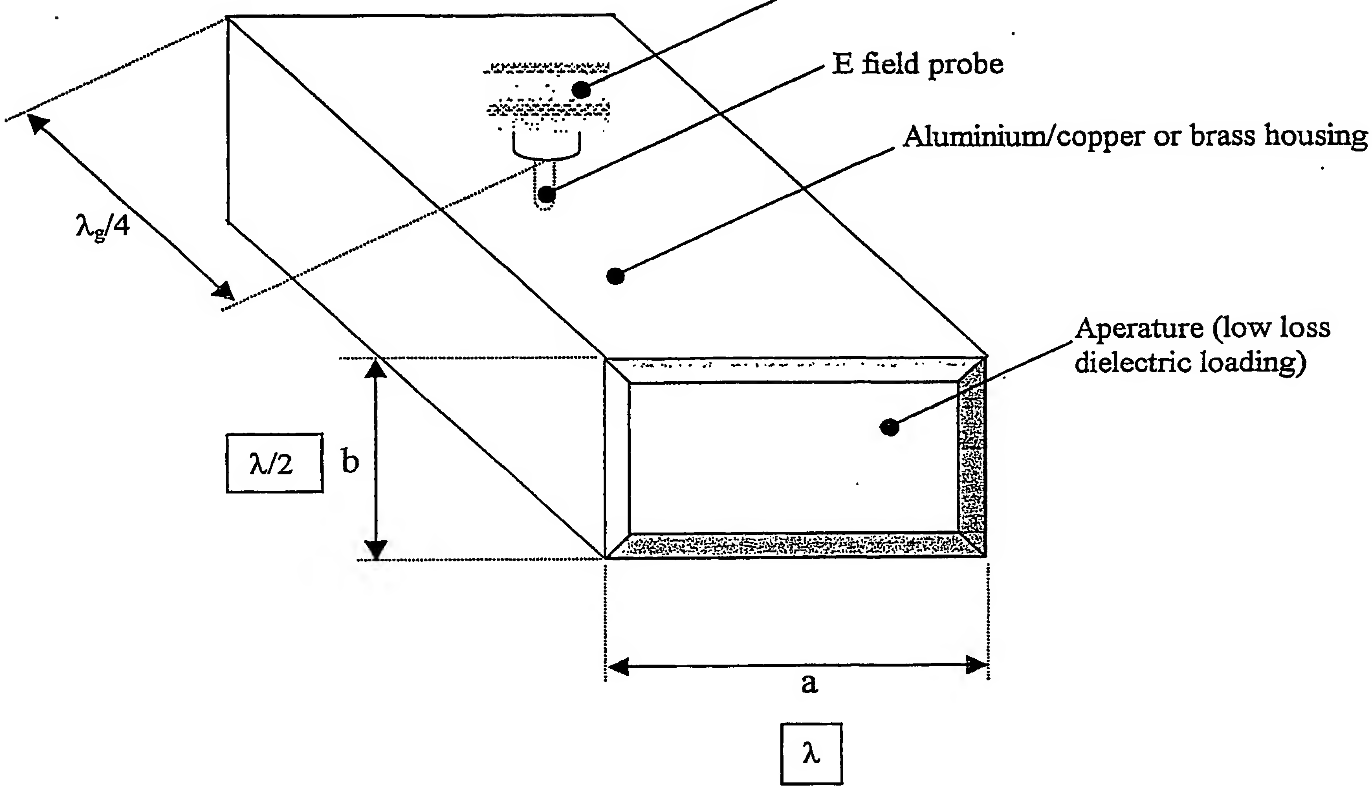


Figure 10: Waveguide instruments

Rectangular loaded structures:




In this instance, a $TE_{21}$ mode would propagate

Cylindrically loaded structures: